Flight Dynamics Technologies
Work Area 5710

GSFC/SOMO Technology Development Program
FY01 Annual Review

Thomas Stengle

September 19-20, 2001

Agenda

•Work Area Overview

•Task Overviews (Goal, Benefit, Potential Customers, Approach, Status, Plans, Partnerships, Transfer Plan, Commercialization Potential)

5711 - Navigation Technology Enabling Future Missions (Russell Carpenter)
5712 - Flight Dynamics Automation Systems Program (Joe Toth)
5713 - Formation Flying Technology (Jesse Leitner/Steve Hughes)
5714 - Advanced Mission Design (Dave Folta)
5715 - Advanced Attitude Determination & Sensor Calibration (Rick Harman)

•Work Area Milestone Summary

5710 Flight Dynamics Technologies

Work Area Overview

•Objectives

•Develop techniques and tools which enable a distributed network of individual autonomous vehicles to act collaboratively as a single collective unit exhibiting a common system wide capability;
•Develop techniques to support autonomous navigation and onboard navigation systems;
•Develop advanced techniques in the areas of trajectory design and attitude determination;
•Develop and infuse advanced mission design technologies, which enable rapid and robust mission design planning, contingency analysis, and new types of missions;
•Dramatically reduce mission operations costs through the elimination of costs associated with flight dynamics product generation functions; and to
•Research, develop, and implement improvements to attitude determination and sensor calibration techniques with the goal of ground processing automation or spacecraft on-board automation.

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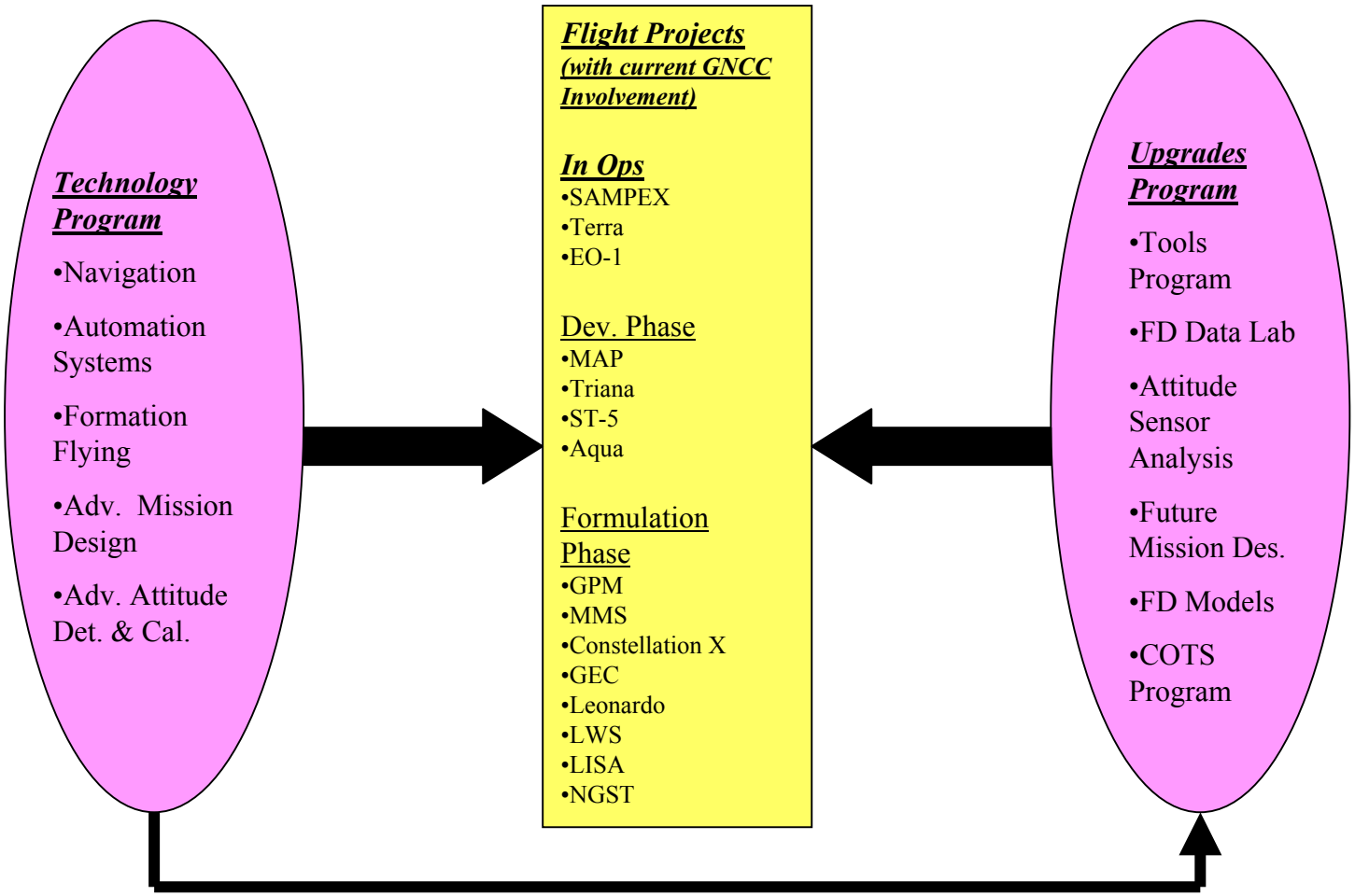
- ***Heavy GNCC involvement in a wide variety of flight projects assures infusion and relevance of new technology***
- ***Significant coupling between SOMO Technology and Upgrades Programs***



5710 Flight Dynamics Technologies

Work Area Overview

- **Summary of *Significant Events* Since Semi-Annual Review (Technical)**
  - – EO-1 successfully demonstrates autonomous formation flying (while the flight demonstration was not funded by SOMO, previous SOMO funded activities laid the groundwork for this flight demonstration
  - – GEODE successfully integrated in ITT Low Power Transceiver (LPT) and GSFC PiVoT GPS receiver
  - – Provisional patent application filed for MATLAB-ADS software system (uses algorithms developed under task 5715)
  - – Dynamic Systems Theory work experience applied to supporting MAP mission design
  - – MAGNAV ready to fly on WIRE (expected by September 30, 2001)
  - – Orion nanosat development completed (end of SOMO funding for this effort)

Work Area Overview

- **Summary of *Significant Events* Since Semi-Annual Review (Program Management)**
  - – FY01 Funding reduced in Automation Studies (Task 5712); work focused (but delayed) on university activities
  - – Notification of loss of SOMO funding for flight dynamics technology activities in FY02; considerable replanning of work, negotiations with support contractors on appropriate close down of activities
  - – Contracting approach changed for many activities (work moved from IDIQs to GSFC MSES contract)
  - – GSFC Distributed Spacecraft Systems (DSS) Tiger Team recently completed activities; provided consolidated picture and technology map of DSS activities; skill mix needs and funding sources (Code R, SOMO, Code Y, Code S, DDF, IRAD) being defined; will use any available SOMO funding for higher level DRLs
  - – Inhouse capabilities within the Flight Dynamics Analysis Branch continued to grow; hiring efforts successful

5710 Flight Dynamics Technologies

Work Area Summary

- **The last third of FY01 has been highly disruptive from a program management point of view**
- **Overall, milestones in the work area plan have been met**
  - Tasks 5712 (Automation Studies) and 5715 (Advanced Attitude) had impacts due to SOMO funding cuts at mid year
  - With uncertainties in FY02 funding, work in Task 5711 (Navigation) modified somewhat to stretch work into FY02 and adjust priorities so that support to LPT and PiVoT host were given priority
  - Activities for 5713 (Formation Flying) came to a logical close (Orion, APL CLT) and replanning efforts are underway
- **With shift of prime funding source for future technology work from SOMO to Code S and Code Y, we will be working in early FY02 to understand funding levels and make sure our plans line up with new customer needs. More direct ownership by Code S and Code Y of technology work is a positive outcome of the loss of SOMO funding.**
- **Work area planning is currently underway based on some assumed funding levels**

Task 5711

Navigation Technology Enabling Future Missions

5711 Advanced Navigation Enabling Future

- **Goals**
  - **To develop and infuse autonomous navigation technologies for Earth orbiting, libration point, and deep space missions**
  - **To enable highly accurate autonomous onboard inertial and relative navigation for multiple satellites**
  - **To reduce the cost of autonomous navigation implementation and testing while increasing the efficiency of the navigation process**
  - **To provide formation missions with a real-time capability to determine the relative positions of the individual segments by using tracking data measured from crosslinks and/or GPS**
  - **To use onboard attitude sensor measurements, new algorithms, and high fidelity environmental and filter models to accurately determine the spacecraft state**

5711 Advanced Navigation Enabling Future Missions

- **Benefits**
  - **Enables Advanced Mission Concepts**
    - **Formation Flying**
    - **Solar Sailing**
    - **Low Thrust**
    - **Cross Link Navigation**
  - **Enables Autonomy for all aspects of Navigation including**
    - **Maneuver Planning & Execution**
    - **High precision orbit determination and prediction achievable**
    - **Communication signal acquisition**
    - **Definitive navigation data with science telemetry**
    - **Realtime updates to attitude subsystem**
  - **Multi-thread approach provides unified solutions for all missions**
    - **Traditional Doppler/range measurements not necessary**
    - **Can use GPS, TDRSS, GN, DSN measurements**
    - **Can use attitude sensor measurements**
    - **Applicable to LEO, HEO, GEO, Libration Point, Deep space missions**
  - **Provides cost-saving solutions**
    - **minimizes ground operations & tracking operations**
    - **low impact on spacecraft implementation**
    - **optimizes use of available attitude and navigation sensor data on the satellite**

5711 Advanced Navigation Enabling Future Missions

- **Potential Customers**
  - **NASA strategic mission operation needs**
    - **Increased automation -> Reduced mission design costs and risk as well as greater consistency and reliability and direct science benefit**
  - **Codes Y, S, and M, as well as DoD and commercial vendors, have requirements for constellations and formation flying that are either enabled or enhanced by this technology**
  - **Can be used for Space as well as Earth science formation missions; applicable to low, medium, and high Earth orbits as well as libration point and deep space missions**
  - **Useful for distributed spacecraft missions and sensor webs**
  - **Enables "lights-out" operation of multiple satellites flying in formation**
  - **SMEX, MIDEX -> Provides an absolute navigation capability**
  - **Increased automation -> Provides optimal use of onboard communication devices for a power, weight savings over stand-alone navigation systems.**
  - **Constellation/Formation support -> Analyses simulate data from planned NASA missions in different orbit configurations (LEO, HEO, Libration, deep space)**
  - **Any HEO mission (AMM, MMS) and any libration orbit mission (NGST, MAP, Constellation-X)**

5711 Advanced Navigation Enabling Future Missions

- **Approach**
  - A multi-purpose navigation software package that maximizes software reusability and maintainability, and can be easily reconfigured to a user's needs (GEONS)
  - Use of heritage code to reduce errors and assure reliability and compatibility
    - Based on flight-proven ground-based (GTDS) & onboard (TONS/GONS) navigation systems
    - Common software package (GEONS) tailored to specific applications via compile and/or run time options (except as noted)
  - Use of realistic simulation data and actual satellite data for analysis & testing
    - Includes actual satellite data from EUVE, Terra, Polar & SOHO
    - H/W in the loop testbeds: GPS signal simulator and closed-loop orbit control, TDRSS User RF Test Set (TURFTS)
  - Measurements include:
    - GPS
    - FAA WAAS
    - Intersatellite crosslinks
    - Ground station
    - TDRSS
    - Star, Sun, Lunar, and Earth Sensor Measurements
    - Forward-link Doppler Measurements From Command Link Carrier
  - Integrated testing between hardware and software
  - GPS target platforms: in-house open-architecture GPS receiver (PiVoT), and ITT low power transceiver (LPT)
  - Web-based team collaboration, using concurrent version system (CVS) code management

5711 Advanced Navigation Enabling Future Missions

- **Status**
  - Supported successful integration of GEODE
    - ITT Low Power Transceiver
    - GSFC PiVoT GPS receiver
  - HEO mission analysis
    - MMS Phase 4 (10 x 50 RE)
    - MMS Phase 1 (1.2 x 12 RE)
    - Magic (selected as GFE for proposal)
  - Completed and tested initial release of GEONS (GPS+crosslink capability)
  - Processed EO-1 GPS data
  - Studies of numerous options for measurement and estimation techniques performed for MEO formation (Auroral Lights), a scenario w/extremely low relative dynamics
    - Simultaneous vs. independent estimation
    - GPS vs. crosslink
    - Various GPS options: standard pseudorange, pseudorange + range bias estimation, single-differenced pseudorange
  - Crosslink signal noise is leading error in relnav solutions
  - Simplest technique, i.e. independent solutions using GPS standard pseudorange found to be as good as more complicated techniques (~1 m, 1 mm/sec)
  - Added 1-way Doppler to GEONS
  - Processed Tracking and Sensor Data for Polar and SOHO Spacecraft

5711 Advanced Navigation Enabling Future Missions

- **Plans**
  - **Incorporate receiver aiding and cold-start algorithms developed by partners (CU/Boulder, Purdue)**
  - **Continue to update MMS and Magic analysis based on latest mission orbits and attitude profiles**
  - **Incorporation of Celnav into GEONS**
  - **Relative navigation analysis for Constellation-X type mission**
  - **Incorporation of simple maneuver capability (Lambert targeting)**
  - **Decentralized estimation & control for formations**
  - **Magnetometer-based coarse navigation for initialization**
  - **GPS Attitude Determination capability**
  - **INS aiding**

5711 Advanced Navigation Enabling Future Missions

- **Partnerships and Collaborations (if any)**
  - **Code S Explorers Technology Development (NRA 98-OSS-10)**
    - Leitner, Carpenter, Axelrad (CU), Garrison (Purdue), “Open architecture receiver for autonomous GPS navigation and formation flying in all Earth orbiting Explorer missions”
    - Stadter (APL), Gramling, “Cross-link communications and navigation system for multiple distributed spacecraft”
  - **Univ of Colorado/Boulder**
    - GPS Navigation Development
  - **University of Texas at Austin**
    - GPS Attitude Determination & INS aiding
    - Maneuvering capability
  - **Computer Sciences Corporation**
    - Development partner for GPS Nav, EONS, Rel Nav, Cel Nav
    - EONS flight software developer
    - Test/simulation data developer
  - **ITT**
    - GPS/TDRSS/GN low power transceiver developer
    - GEODE flight software integration

5711 Advanced Navigation Enabling Future Missions

- **Infusion and/or Transfer Plan**
  - **GEODE flight qualified for Lewis mission**
  - **GEODE Lite flight demonstrated on EO-1**
  - **GEODE transferred to LaRC for evaluation of use by Picasso/CENA (ESSP)**
  - **GEONS & PiVoT selected for GFE navigation by Magic mission proposal**
  - **Potential use of GEODE used on proposed Earth Science missions (MMS, Auroral Lights) under discussion with scientists and project engineers**
  - **Plan to solicit missions based on Terra success for EONS**
  - **Current analyses using Aurora Lites, MMS for Relative Navigation mission studies**
  - **CelNav system can be used for ground based navigation**
  - **CelNav "Flight Code" may be included in Discovery mission**

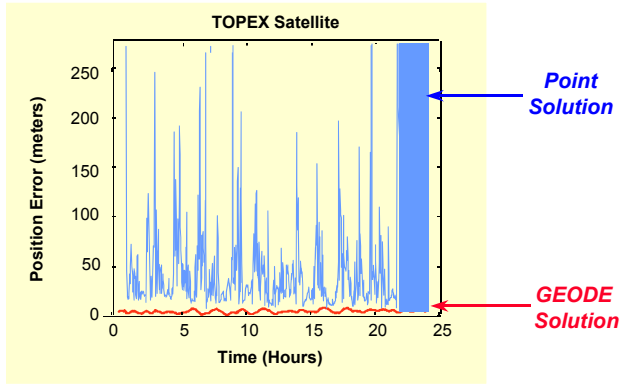
5711 Advanced Navigation Enabling Future Missions

- **Commercialization Potential/Plan (if any)**
  - **GEODE licensed to Orbital Sciences Corporation for use on OrbComm**
  - **GEODE licensed to Ball**
  - **OSC expressed interest in embedding GEODE filter into a space-qualified version of their Ashtech G12 GPS receiver**
  - **License agreement in place with MIT/Lincoln Labs via DoD**
  - **License agreements are in negotiation with UCLA & CU/Boulder**
  - **Agreement with ITT for infusion into Low Power Transceiver for Shuttle demo**
  - **GEODE won GSFC Software of Year, NASA Software of Year Runner-Up**
  - **EONS/GEODE potential for commercialization by Motorola in their receiver units**
  - **Relative Navigation potential for commercialization when integrated with crosslink receiver (APL, Motorola, ITT)**
  - **CelNav potential for commercialization when integrated with GEODE, RelNav or EONS**

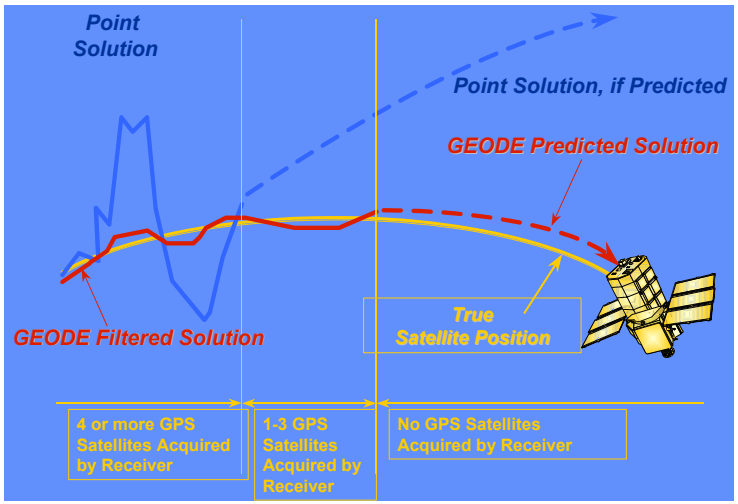
Flight Dynamics Technologies

GPS Navigation

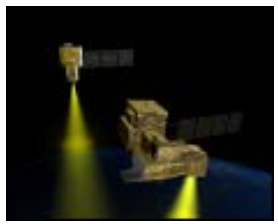
- Global Positioning System (GPS) satellite navigation is a proven technology that provides potential for low-cost autonomous satellite navigation systems.

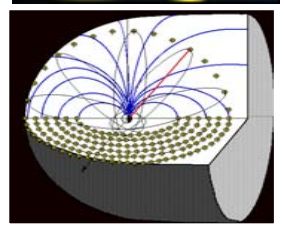


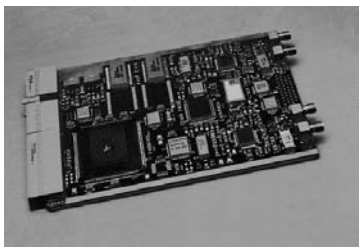
GEODE provides factor of 15 improvement in position accuracy



- The current GPS algorithms, software, receiver hardware, and simulators, however, need to be enhanced to broaden the mission scope to include all near-Earth missions, such as highly elliptical orbits (HEO) and geosynchronous Earth orbits (GEO), as well as to support relative navigation for formation flying applications.



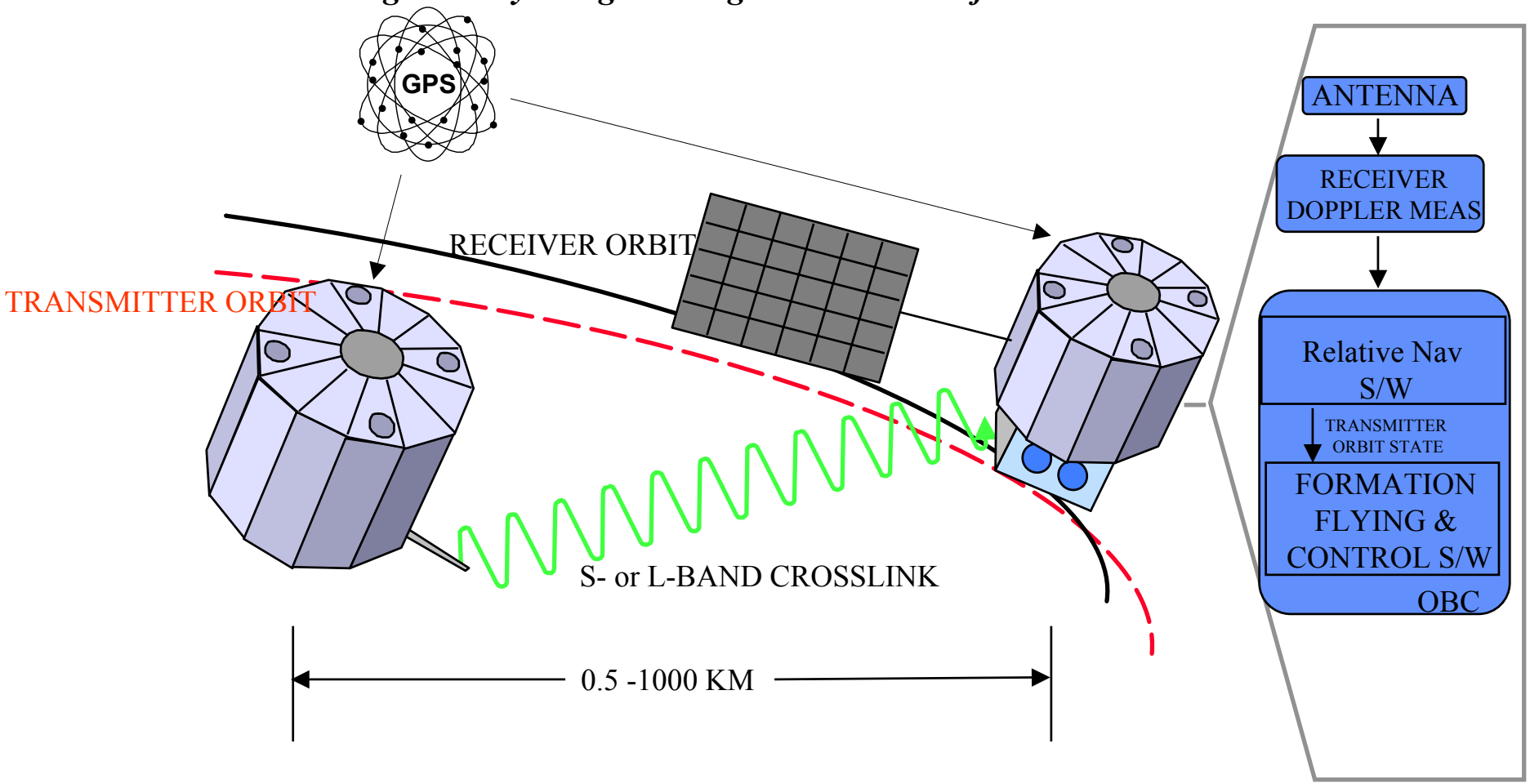




- This project will enhance the GPS Enhanced Orbit Determination Experiment (GEODE) flight software to support such missions, and support its integration with one or more prototype GPS space receivers.

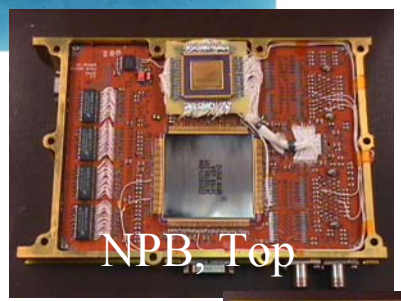
Relative Navigation

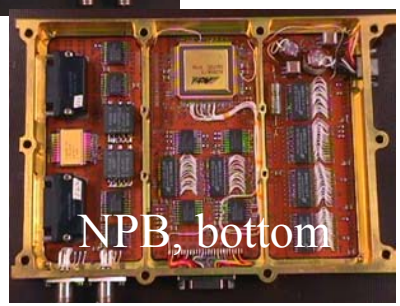
Provide formation missions with a real-time capability to determine the relative positions of the individual segments by using tracking data measured from crosslinks and/or GPS.



EONS: Onboard Navigation In A User's Receiver

EONS is an integrated navigation system, which can be procured as an option to the existing spacecraft communications equipment. For those requiring autonomous navigation, EONS will be significantly cheaper and more reliable than independent software development and system integration efforts. EONS is derived from TONS, which flew on EUVE and Terra. It has been integrated into a Nav Processor Board (NPB) that will be part of Motorola's 4th Generation Transponder.





OBJECTIVE: To integrate comprehensive navigation software into a multi-frequency receiver to provide accurate navigation products for users with wide-ranging mission designs.

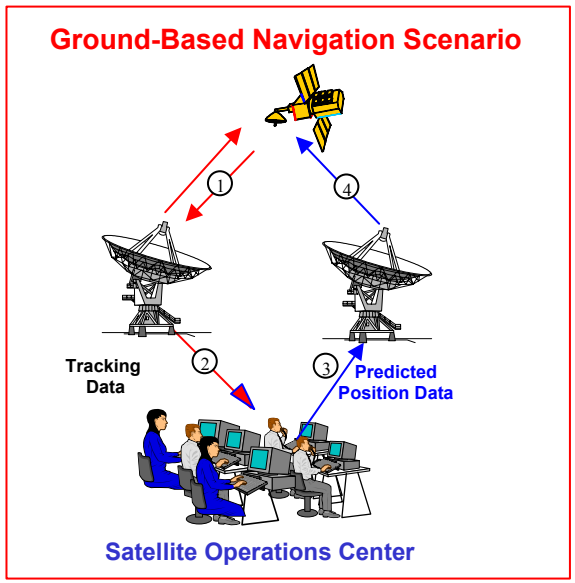
As host to the GEONS software, the multi-frequency receiver will provide the space platform with navigation products based on flight proven heritage design and processing. This integrated package alone will support users from low-earth to highly-elliptical to libration point orbits; users of GPS, ground stations, TDRSS, and/or crosslink signals for absolute and relative navigation; and solo, constellation, or formation missions.

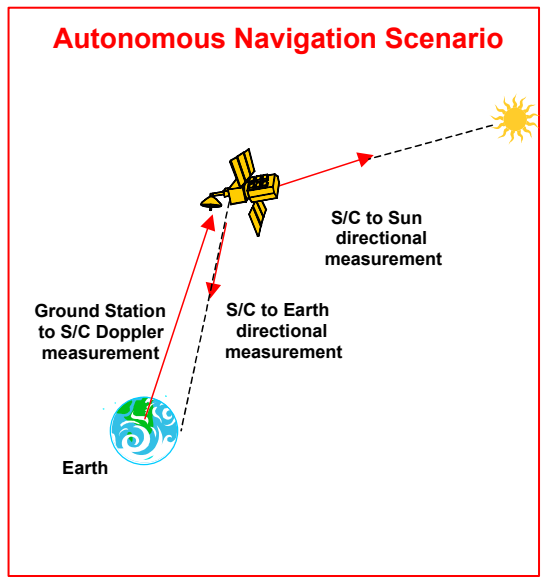
The benefits to this approach are realized in both the spacecraft development and ground system support. By maximizing the use of flight hardware required onboard for communications, a multi-frequency receiver with GEONS processing provides proven autonomous navigation capabilities and a necessary quantity for extended autonomous operations such as trajectory control. The "single box" design reduces both spaceflight development and ground system operations costs and time.

Flight Dynamics Technologies

Celestial Navigation

The Celestial Navigation of spacecraft opens up high earth, libration point, and deep space missions to autonomous navigation. Celnav is a simulation/navigation system that uses onboard attitude sensor measurements, new algorithms, and high fidelity environmental and filter models to accurately determine the spacecraft state. Autonomous navigation has the potential both to increase spacecraft navigation system performance and success and to reduce total mission cost.





Task 5712

Flight Dynamics Automation Systems Program

5712 Flight Dynamics Automation Systems Program

- **Goal**
  - **To dramatically reduce mission operations costs through the elimination of costs associated with flight dynamics product generation functions.**
- **Benefit**
  - **By automating flight dynamics products generation, mission costs can be significantly reduced and lights out operations become possible. This will be a requirement to make multiple spacecraft missions reasonably priced.**
- **Potential Customers**
  - **All NASA enterprises.**

5712 Flight Dynamics Automation Systems Program

- **Approach**
  - Working with university and industry partners towards the implementation of lights out flight dynamics product generation.
  - Use SAMPEX flight dynamics operations at the University of Maryland as a test bed
- **Status**
  - Mid year withdrawal of funds has resulted in curtailment of most activities
  - Flight Dynamics Control Laboratory/University of Maryland
    - 2.1 Continue parallel capability: Completion scheduled for 2Q FY02. Currently running parallel tests using old and new systems. Initial tests yield same results. Improvement of user interface underway. Enhancement of tracking data conversion methodology underway.
  - OrbitServer: Commercial Flight Dynamics Product Generation Tool/AI Solutions
    - 2.2 Enhance tool with learning capability: Work halted at start of 1Q FY01.
    - 2.3 Add new rule base searching capabilities including genetic algorithm: Work halted at start of 1Q FY01.
  - Automated Intelligent FD Product Generation Tool /University of Maryland
    - 2.4 Pre-processing and uploading of tracking data: Completed 3Q FY01.
    - 2.5 Orbit determination based on tracking data: Completion scheduled for 3Q FY02.
    - 2.6 Post-processing of orbit determination results into various products; sending the products to their intended recipients: Currently in middle of producing first product. Completion scheduled for 1Q FY03.

5712 Flight Dynamics Automation Systems Program

- **Plans**
  - **Flight Dynamics Control Laboratory/University of Maryland**
    - **2.1, 2.4, 2.5 and 2.6: Delivery scheduled by 1Q FY03.**
      - **The automation will have a graphical user interface accessible through a web browser which will allow a user to observe the status of the process, obtain the latest results, and to modify the products produced including where certain products should be sent to, as well as when this should occur. This will be done so as to automate the current manual process as well as being flexible enough to address future products.**
  - **OrbitServer: Commercial Flight Dynamics Product Generation Tool/AI Solutions**
    - **2.2 and 2.3: Delivery due 18 months after start of funding.**
      - **Develop visualization tools that demonstrate autonomous flight dynamics operations, product generation and distribution, and provide an overall management view of the status of the flight dynamics automation system.**
      - **Design the architecture to provide for future expandability including inadaptability to the SMEX class of NASA Missions.**
      - **Demonstrate autonomous control, operations and product generation for the WIRE spacecraft.**
      - **Demonstrate autonomous pattern recognition and fault recovery for tracking data and selected spacecraft health and safety data such as attitude, etc.**

- **Partnerships and Collaborations**
  - **National Aeronautics and Space Administration Research Grant #NAG5-10563 with the University of Maryland College Park for the "Automation of SAMPEX Orbit Determination."**
  - **Contract with a.i. solutions under NAS 5-01090.**

5712 Flight Dynamics Automation Systems Program

- **Infusion and/or Transfer Plan**
  - Industry and academic partners working within the program will infuse and transfer technology to the GN&C by bringing together researcher, developers and users.

- **Commercialization Potential/Plan**
  - Potential exists to make technology available to industry through their participation in the program.
  - Transfer technology directly to NASA/GN&C customers.

Task 5713

Formation Flying Technology

5712 Formation Flying Technology

Opening Notes:

- **TWO MAJOR SUBTASKS FUNDED BY SOMO**
  - **–Orion Formation Flying demonstration (emphasizes inter-spacecraft communications and relative navigation and also addresses formation flying architectures, strategies, and control approaches)**
  - **–APL's Crosslink Transceiver (emphasizes techniques and subsystems which enable inter-spacecraft communications and relative navigation)**

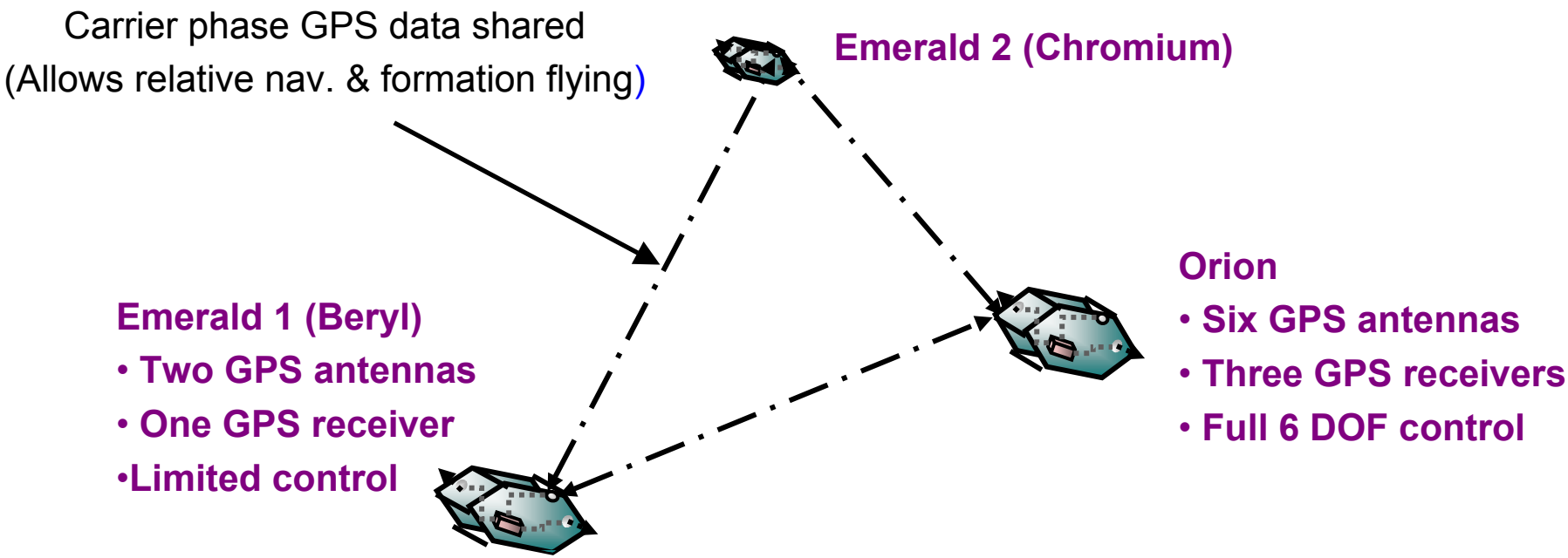
- **PLANNING ACTIVITIES**
  - **–A significant activity during the past three months was the replanning of DSS activities and reassessment of DSS technologies that are required for future missions**
  - **–Tiger team responsible for this replanning had representatives from across the Goddard AETD organization**
  - **–An effective and comprehensive roadmap is now in place; this will guide future activities and requests for funding from multiple sources**

5712 Formation Flying Technology: Orion Nanosat

- **Goal**
  - Demonstration of key formation flying technologies on a trio of nano-satellites
- **Benefit**
  - Advance the TRL level of key concepts for formation flying missions, including intersatellite communications and ranging, relative navigation, and formation control.
  - Develop capability within key universities to develop highly-capable low-cost nanosats
- **Potential Customers**
  - Code S and Code Y - Distributed spacecraft missions
  - Code M - rendezvous and docking for shuttle and ISS applications
- **Approach**
  - Use university and DoD partners for low-cost, high risk demonstration of key distributed spacecraft technologies in the short term.
- **Status**
  - Has passed all but final shuttle safety inspections and AFRL configuration management review. Set to begin integration into Nanosat-1 pallet at AFRL before the end of CY01.
- **Plans**
  - After integration, shuttle launch will be manifested. Launch likely in late 2003.
- **Partnerships and Collaborations**
  - Joint activity with AFRL, NASA Portion co-funded with Code R DSS funding
- **Infusion and/or Transfer Plan**
  - Lessons learned from spacecraft integration or flight will be infused into the analysis and development of NASA's array of DSS missions.

Formation Flying Technology
The Orion Microsatellite Mission

- **Formation Flying Testbed**
- **Comprehensive on-orbit demo of** true formation flying
  - Develop technologies to build a ***virtual spacecraft bus***
  - GPS sensing & fleet control



5712 Formation Flying Technology: APL CLT

- **Goal**
  - Advance RF communications technology to ensure readiness for upcoming distributed spacecraft missions.
- **Benefit**
  - Enable availability of low-cost RF intersatellite communication systems
- **Potential Customers**
  - Code S and Code Y - Distributed spacecraft missions
  - Code M - rendezvous and docking for shuttle and ISS applications
- **Approach**
  - Develop and validate engineering models and RF component technology and systems issues
- **Status**
  - Key elements completed - have enabled a low-cost (< $400k) contract (Code R) funding for three CLT units to support the Nanosat-2 ION-F mission. This compares to costs between $1M and $5M for comparable units for related programs such as TechSat-21
- **Plans**
  - Contract is in place (Code R funding) and development is moving forward for the 3 CLT units which will be delivered for integration into ION-F by January 2002.
- **Partnerships and Collaborations**
  - Joint activity with AFRL, NASA Portion co-funded with Code R DSS funding
- **Infusion and/or Transfer Plan**
  - Technology will be handed off to the DSS Intersatellite Comm working group at Goddard to identify which missions after University Nanosats are appropriate for this technology.

5710 Flight Dynamics Technologies

5712 Formation Flying Technology: Planning Activities

- **Sample of DSS Technology Map (Remote Sensing and Control Area)**

Formation Sensing and Control (Jesse Leitner, 571, x2630)				
Subarea:	**Relative navigation and metrology (High/Med/Low precision)**			
	Strategic need	*Ongoing activities (TRL)*	*Current GSFC role*	*Future GSFC Role*
Technologies				
I. optical ranging/comm hw				
IA. Laser metrology systems	MAXIM, SI, MAXIM PF, SPECS will all need nano-performance sensing systems	JPL activities?	?	perhaps
IB. Optical APD hw	CON-X has somewhere between RF and optical requirements, likely achievable by optical APD	SBIR Phase II with Visidyne (2)	COTR	COTR
II. RF ranging/comm hw				
IIA. enhanced GPS receivers	MMS, MTC, Auroral LITES are just at the border of capability to use GPS	Explorers high altitude relative nav with PiVoT/GEODE (2-5)	Developers, testing in sim	integration into flight programs
IIB. enhanced TDRSS receivers	possibility for missions with mild requirements such as DRACO	Gramling's work with Motorola (5)	COTR	high TRL testing
III. adv nonlinear estimation algs.				
IIIA. high fidelity, model-based estimation algorithms and filters	most missions with formation flying	GEODE (5)	developing, testing, transitioning	optimizing software, updating models
IIIB. robust, adaptive, estimation filters	most missions with formation flying	J. Deutschmann's PhD work (1)	basic research	high fidelity simulations, tests in realistic environments
IV. WFE-based navigation/metrology				
IVA. real-scene wavefront sensing	maybe the only solution for missions such as SI and MAXIM	new SBIR topic (1)	subtopic manager	developing/testing algorithms
IVB. development of transformations from wavefront error to satellite position/orientation errors	necessary for IVA	new SBIR topic (1)	subtopic manager	developing/testing algorithms
VI. Integrated navigation algorithms				
VIA. Integrated GPS/INS algs	high altitude missions, borderline out of GPS range, such as MMS, MTC, etc	basic research for space (1)	none	development, grants, etc.
VIB. Integrated GPS/CELNAV	high altitude missions, borderline out of GPS range, such as MMS, MTC, etc	none	none	development, grants, etc.
VIC. Formation INS concepts	libration point and deeper missions	kilometric gyro (?)		

Task 5714

Advanced Mission Design

5714 Advanced Mission Design

Goal

- Develop and infuse advanced mission design technologies to enable rapid and robust mission design planning, contingency analysis, and new types of missions.

- Primary goal to reduce operations cost while providing a highly accurate system to increase the efficiency of the orbit design process

Benefit

- Provides a tremendous time savings in trajectory design.
- Robustness in trajectory design, especially for libration orbit design
- Application to contingency analysis and post launch support
- Innovative classes or mission orbits to support science goals
- Reduce or eliminate libration orbit stationkeeping /momentum maneuvers

5714 Advanced Mission Design

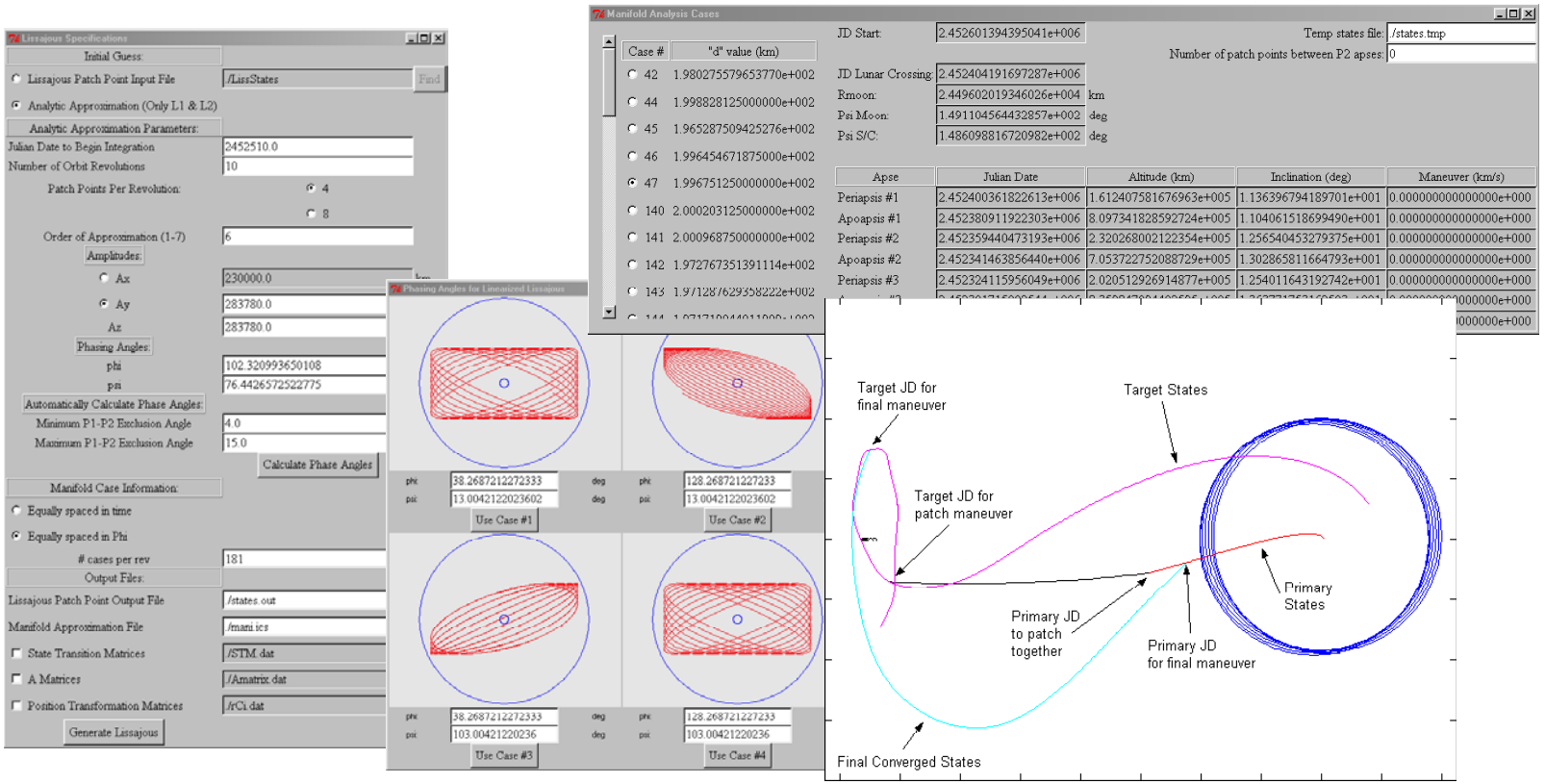
- **Potential Customers**
  - Continue use for GSFC LWS, SEC, NGST, Triana, and Origins programs.
  - JPL / JSC for HEDS and Libration Orbit design.
  - Purdue University and other universities for academics.
  - Commercial interest (SES, TRW, Lockheed for NGST)
- **Approach**
  - **Technical**
    - Develop algorithm, prototype/finalize code, and write mathematical specifications for integration into a GN&C matlab based system.
    - Design trajectories using DST and advanced numerical techniques.
    - Follow an iterative prototyping approach, with frequent user demonstrations, feedback, and revisions based on user input..
    - Techniques (solar sail accelerations, etc.) and linear and non-linear feedback control.
    - Incorporate MATLAB optimization utilities and algorithms.
  - **Programmatic**
    - Weekly status and planning reviews via email and teleconferences.
    - Quarterly updates to algorithms and mathematical specifications.
    - Use of Triana and NGST missions as test bed.

5710 Flight Dynamics Technologies

5714 Advanced Mission Design

- **Status: Work has been completed with delivery:**
  - **Program uses Windows, Matlab, and 'C' for the GUI and internal code.**
  - **Mathematical Specifications and Users Guide**

- **Finalized utility. Sample delivered system GUI shown below**



5714 Advanced Mission Design

- **Plans**
  - Complete investigation of stable quasi-periodic motion for minimizing or eliminating maneuvers.
  - Complete investigate of heteroclinic and homoclinic transfers for libration orbit mission design
  - Complete optimization task and implement algorithms.
- **Partnerships and collaborations (if any)**
  - Purdue University and a.I.-Solutions inc., Provide basic research, mathematical algorithm development, utility applications, and 'support'.
  - Demonstrated to Triana and NGST projects.
  - ISC (code 583) developed a preliminary matlab version.
  - Inclusion of work In libration orbit formation flying team with JPL and JSC.
  - NASA academy student research used DST results.
- **Infusion and/or transfer plan (if any)**
  - The DST manifold method has been incorporated into several missions.
  - Formal tool development for possible educational use.
- **Commercialization potential/plan**
  - Analytical graphics contacted Purdue regarding potential applications in AGI's satellite toolkit (STK) and astrogator, a COTS product.
  - Possible further independent development by Purdue University.

Task 5715

Advanced Attitude Determination & Sensor Calibration

5715 Adv. Attitude Determination & Sensor Calibration

- **Goal:**
  - **Improve Accuracy of Attitude Estimation and Sensor Calibration**
  - **Decrease Operations Costs by Attitude Estimation and Sensor Calibration Automation (ground and onboard systems)**
- **Benefit:**
  - **Improved accuracies for science missions**
  - **Reduced operations costs**
- **Potential Customers:**
  - **NASA and commercial spacecraft**
- **Approach:**
  - **Research and implement algorithms to improve attitude estimation and sensor calibration**
  - **Research and implement algorithms which automate ground attitude estimation and sensor calibration**
  - **Research and implement algorithms which provide for onboard sensor calibration**

5715 Adv. Attitude Determination & Sensor Calibration

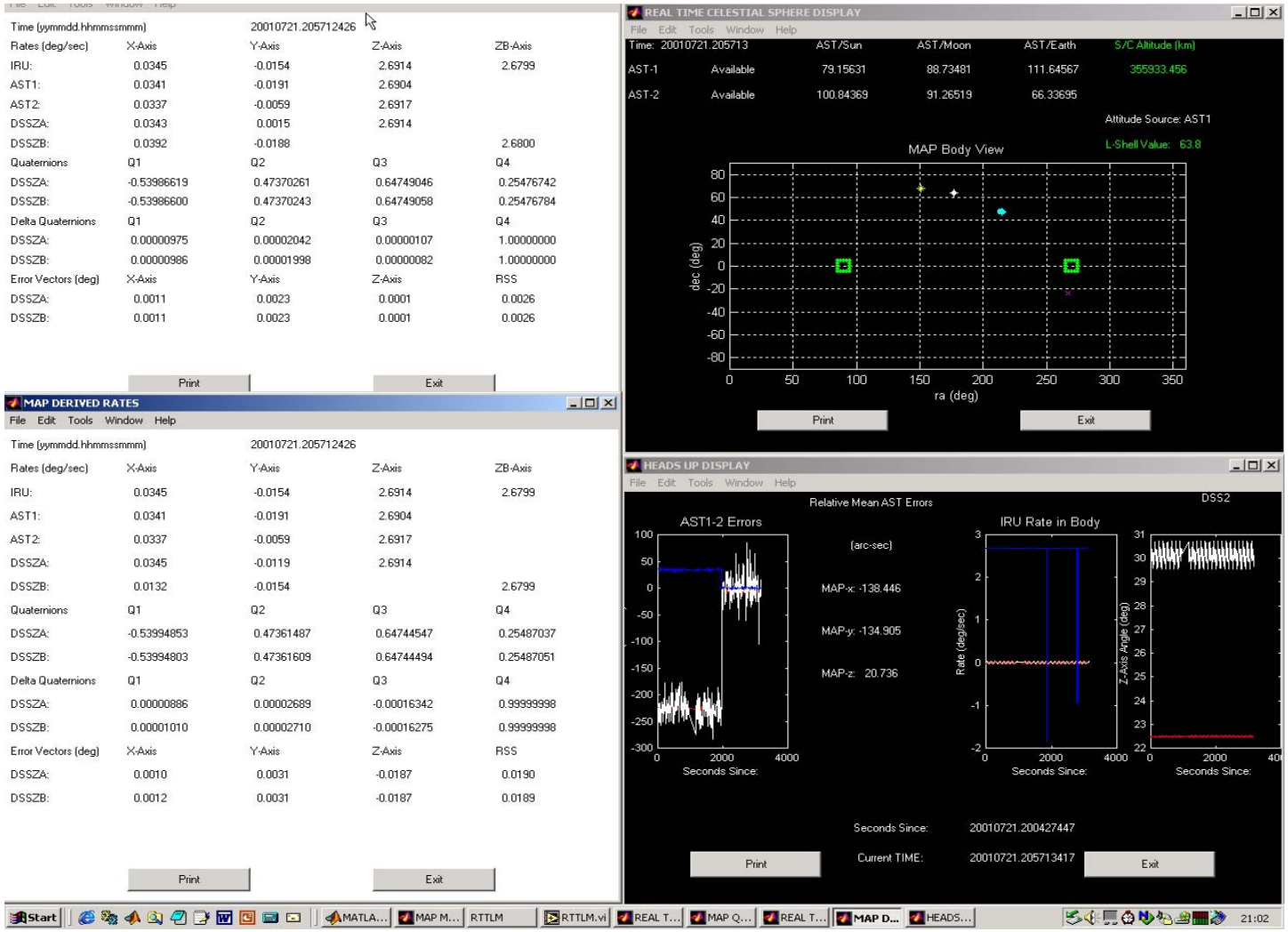
- **Status:**
  - **MAGNAV Test Flight Still Scheduled for 4Q FY01**
  - **Attitude Estimation Automation Test Concept with MAP Delayed to 2Q FY02 due to longer IOC period than planned**
  - **AQUA Gyro Calibration Algorithm has been fully developed and tested and final operations package scheduled for 4Q FY01**
  - **Multi-Mission Spin Stabilized System Enhancement Delayed to 3Q FY02.**
  - **Multi-Mission Spin Stabilized/Three Axis System Combination Concept Still Scheduled for 4Q FY01**
  - **LQR Method for Gyro Calibration is Still Being Tested with MAP Flight Data**
  - **Gyro Calibration Automation Batch Method Concept delayed till 1Q FY02.**
  - **Attitude and Rate Estimator was Successfully Used in MAP mission as OBC backup during each perigee burn**

5715 Adv. Attitude Determination & Sensor Calibration

- **Plans:**
  - **Future work will concentrate on onboard sensor calibration**
- **Partnerships and Collaborations:**
  - **Dr. Mark Psiaki of Cornell Ground MAGNAV research cancelled due to earlier SOMO cuts**
  - **Dr. Jeremy Kasdin of Princeton results on Two-Step Attitude Estimation Technique delayed (no extra cost) till 2Q FY02**
- **Infusion and/or Transfer Plan:**
  - **MAP specific attitude and rate estimation algorithm operational and in use with Real Time Attitude Determination System**
  - **AQUA Gyro Calibration Algorithm Scheduled to be delivered to AQUA analysts 4Q FY01**
- **Commercial Potential Plan:**
  - **Provisional Patent application has been completed for both the Multi-Mission Three Axis Stabilized Spacecraft (MTASS) and Multi-Mission Spin Stabilized Spacecraft (MSASS) Attitude Systems**
  - **Two Commercial Companies have expressed interest in MTASS and MSASS. One company has plans to sign commercial agreement with NASA/GSFC and will use system to support upcoming military contract involving multiple satellites.**

5715 Adv. Attitude Determination & Sensor Calibration

- **MAP Real Time Results (derived rates on left, bottom right plot shows relative Star Tracker (AST) Alignment Errors going to approximately 0 (with noise) after uplink of MTASS Generated alignment matrix)**



5710 Flight Dynamics Technologies

Milestone Schedule

GSFC / SOMO FY01 TECHNOLOGY DEVELOPMENT PROGRAM
DELIVERABLES BY TASK

WORK AREA	DELIVERABLES (Sorted by Work Area and Task Number)	DATE from WAP	Status	Comments
5710	**ADVANCED GUIDANCE, NAVIGATION AND CONTROL (AGNC) WORK AREA**			
5710	**5711 - Navigation Technology Enabling Future Missions Task**			
5710	***GPS Navigation***			
5710	1.1 Develop HEO/GEO capability in GEODE	1Q FY01	Completed	
5710	1.2 Receiver aiding	4Q FY01	ON SCHEDULE	
5710	1.3 Host to Receiver --- Pivot	1Q FY01	3Q FY01/Completed	#4
5710	1.4 Host to Receiver --- LPT	3Q FY01	2Q FY01/Completed	
5710	1.5 Flight qual/demonstration: EO-1	2Q FY01	Completed	
5710	***Enhanced Onboard Navigation System (EONS)***			
5710	1.6 Doppler Extractor on 4th gen xpdr	4Q FY01	REDIRECTED	AA
5710	***Relative Navigation (RelNav)***			
5710	1.7 Crosslink & GPS Analysis	4Q FY01	ON SCHEDULE	
5710	1.8 Crosslink receiver development: concept & specifications	1Q FY02	FOLDED INTO 1.7	BB
5710	***Celestial Navigation (CelNav)***			
5710	1.9 Design	4Q FY01	ON SCHEDULE	
5710	1.10 Flight data processing	4Q FY01	ON SCHEDULE	
5710	1.11 Integration with GEONS: Specifications	2Q FY01	Completed	
5710	1.12 Integration with GEONS: Development	3Q FY01	1Q FY02	#48
5710	1.13 Integration with GEONS: Testing	1Q FY02	3Q FY02	#48
5710	**5712 – Flight Dynamics Automation Systems Program Task**			
5710	***Flight Dynamics Control Laboratory/University of MD***			
5710	2.1 Continue parallel capability	4Q FY01	2Q FY02	#36
5710	***OrbitServer: Commercial Flight Dynamics Product Generation Tool/AI Solutions***			
5710	2.2 Enhance tool with learning capability	4Q FY01	4Q FY02	#37
5710	2.3 Add new rulebase searching capabilities including genetic algorithms	1Q FY02	FY03	#37
5710	***Automated Intelligent FD Product Generation Tool/University of MD***			
5710	2.4 Automate current manual process with simple rule base	4Q FY01	2Q FY02	#36
5710	2.5 Develop intelligent tool which include learning capability with rule base	1Q FY02	FY03	#36
5710	**5713 - Formation Flying Technology Task**			
5710	***Orion Formation Flying Demonstration/Stanford***			
5710	3.1 Orion spacecraft Critical Design Review	1Q FY01	Completed	
5710	3.2 Implement prototype Orion vehicle	4Q FY01	FLIGHT DELAY	CC
5710	3.3 Launch & operate Orion from Shuttle in formation with Emeralds	1Q FY02	FLIGHT DELAY	CC
5710	***Formation Flying Testbed Development/JHU APL***			
5710	3.4 Integrate software GPS simulation into GSFC FFTB	4Q FY01	Completed	DD
5710	3.5 Complete user interface & visualization portion	4Q FY01	Completed	
5710	3.6 Add support for multiple GPS simulations in hardware	4Q FY01	Completed	
5710	***Inter-spacecraft Communications Strategies and Subsystems/JHU APL***			
5710	3.7 Complete design of CLT for ION-F University Nanosats	2Q FY01	Completed	
5710	3.8 Develop breadboard prototype CLT	2Q FY01	Completed	
5710	3.9 Develop & deliver 3 flight copies to ION-F University Nanosat Team	4Q FY01	FLIGHT DELAY	CC
5710	3.10 Assist in integration and testing of CLT in Nanosats	4Q FY01	FLIGHT DELAY	CC
5710	**5714 - Advanced Mission Design Task**			
5710	4.1 University Dynamical Systems Theory Utility	4Q FY01	Completed	
5710	4.2 Matlab / Mathematica Capabilities	4Q FY01	Completed	
5710	4.3 COTS Enhancement Design	4Q FY01	Completed	
5710	**5715 - Advanced Attitude Determination and Sensor Calibration Task**			
5710	5.1 Four-axes Gyro Calibration: Concept	1Q FY01	Completed	
5710	5.2 Four-axes Gyro Calibration: Demonstration	2Q FY01	Completed	
5710	5.3 Four-axes Gyro Calibraion: Transfer	3Q FY01	Completed	
5710	5.4 Ground-based Magnetometer Navigation: Demonstration	2Q FY01	Completed	
5710	5.5 Onboard Magnetometer Navigation: Demonstration	4Q FY01	ON SCHEDULE	
5710	5.6 GPS-Magnetometer Navigation: Demonstration	4Q FY01	ON SCHEDULE	
5710	5.7 Gyro Calibration (batch technique): Transfer	2Q FY01	Completed	

Work Area Summary

- **The last third of FY01 has been highly disruptive from a program management point of view**
- **Overall, milestones in the work area plan have been met**
  - Tasks 5712 (Automation Studies) and 5715 (Advanced Attitude) had impacts due to SOMO funding cuts at mid year
  - With uncertainties in FY02 funding, work in Task 5711 (Navigation) modified somewhat to stretch work into FY02 and adjust priorities so that support to LPT and PiVoT host were given priority
  - Activities for 5713 (Formation Flying) came to a logical close (Orion, APL CLT) and replanning efforts are underway
- **With shift of prime funding source for future technology work from SOMO to Code S and Code Y, we will be working in early FY02 to understand funding levels and make sure our plans line up with new customer needs. More direct ownership by Code S and Code Y of technology work is a positive outcome of the loss of SOMO funding.**
- **Work area planning is currently underway based on some assumed funding levels**